

## **MATERIALS FOR IMPRINT LITHOGRAPHY**

### TECHNICAL FIELD OF THE INVENTION

**[0001]** One or more embodiments of the present invention relate generally to imprint lithography. In particular, one or more embodiments of the present invention relate to materials for imprint lithography.

### BACKGROUND OF THE INVENTION

**[0002]** Micro-fabrication involves the fabrication of very small structures, for example, and without limitation, structures having features on the order of micro-meters or smaller. One area in which micro-fabrication has had a sizeable impact is in processing of integrated circuits. As the semiconductor processing industry continues to strive for larger production yields while increasing the circuits per unit area formed on a substrate, micro-fabrication becomes increasingly important since micro-fabrication provides greater process control while allowing a reduction in the minimum feature dimension of the structures formed. Other areas of development in which micro-fabrication have been employed include biotechnology, optical technology, mechanical systems and the like.

**[0003]** An exemplary micro-fabrication technique is disclosed in U.S. Patent No. 6,334,960 to Willson et al. In particular, the Willson et al. patent discloses a method of imprint lithography to form a relief pattern in a structure. The method includes providing a substrate having a transfer layer (typically spin-coated), and covering the transfer layer, in turn, with a low viscosity, polymerizable (typically UV curable) fluid composition

(typically in the form of droplets). The method further includes mechanically contacting an imprint template or mold having a relief structure with the polymerizable fluid composition wherein the polymerizable fluid composition fills a gap between the imprint template and the substrate and fills the relief structure of the imprint template. Next, the method includes subjecting the polymerizable fluid composition to conditions to solidify and to polymerize the same (typically, exposing the polymerizable fluid composition to UV to crosslink it), thereby forming a solidified polymeric material on the transfer layer that contains a relief structure complimentary to that of the imprint template. Next, the method includes separating the imprint template from the substrate to leave solid polymeric material on the substrate, which solid polymeric material includes a relief pattern in the form of the complimentary relief structure. Next, the solidified polymeric material and the transfer layer are subjected to an environment to selectively etch the transfer layer relative to the solidified polymeric material to form a relief image in the transfer layer.

**[0004]** The following issues that relate to selective adhesion of the solidified polymeric material to different surfaces are typically considered when one develops a method and/or a material useful in forming fine-feature relief patterns in the solidified polymeric material. First, the solidified polymeric material ought to adhere well to the transfer layer on the substrate, and second, it ought to be easily released from the surface of the imprint template. These issues are typically referred to as release characteristics, and if they are satisfied, the

relief pattern recorded in the solidified polymeric material will not be distorted during separation of the imprint template from the substrate.

**[0005]** In addition to the above-described release characteristics, when designing an imprinting material for use in imprint lithography, further considerations include: (a) low viscosity, for example, and without limitation, a viscosity, at 25°C, of 5 centipoise or less, to fast spread over both the substrate and the surface of the imprint template, and to fast fill the imprinting material into the relief pattern. It is better if the viscosity is sufficiently low so that minimal pressure, for example, and without limitation, a pressure of about 2-4 psi, and no additional heating are necessary to move the imprinting material into the relief pattern on the imprint template; (b) low vapor pressure so that there is little evaporation (evaporation is a problem since the droplets of imprinting material may be on the order of 80 pico-liters, and this results in droplets having a large ratio between surface area and volume); and (c) cohesive strength of the cured imprinting material.

**[0006]** In light of the above, there is a need for imprinting materials for use in imprint lithography that satisfy one or more of the above-identified design criteria.

#### SUMMARY OF THE INVENTION

**[0007]** The present invention is directed to a material for use in imprint lithography that features a composition having a viscosity associated therewith and including a surfactant, a polymerizable component, and an initiator

responsive to a stimuli to vary the viscosity in response thereto, with the composition, in a liquid state, having the viscosity being lower than about 100 centipoises, a vapor pressure of less than about 20 Torr, and in a solid cured state a tensile modulus of greater than about 100 MPa, a break stress of greater than about 3 MPa and an elongation at break of greater than about 2%.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0008]** FIG. 1 is a perspective view of a lithographic system useful in carrying out one or more embodiments of the present invention;

**[0009]** FIG. 2 is a simplified elevation view of a lithographic system shown in FIG. 1;

**[0010]** FIG. 3 is a simplified representation of the material from which an imprinting layer, shown in FIG. 2, is comprised before being polymerized and cross-linked;

**[0011]** FIG. 4 is a simplified representation of cross-linked polymer material into which the material shown in FIG. 3 is transformed after being subjected to radiation;

**[0012]** FIG. 5 is a simplified elevation view of a mold spaced-apart from the imprinting layer, shown in FIG. 1, after patterning and solidification/polymerization of the imprinting layer; and

**[0013]** FIG. 6 is a simplified elevation view of the imprint material disposed on a substrate in accordance with the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

**[0014]** FIG. 1 shows the lithographic system 10 that may be used to carry out imprint lithography in accordance with

one or more embodiments of the present invention and that may utilize imprinting materials fabricated in accordance with one or more embodiments of the present invention. As shown in FIG. 1, system 10 includes a pair of spaced-apart bridge supports 12 having bridge 14 and stage support 16 extending therebetween. As further shown in FIG. 1, bridge 14 and stage support 16 are spaced-apart. Imprint head 18 is coupled to bridge 14, and extends from bridge 14 toward stage support 16. Motion stage 20 is disposed upon stage support 16 to face imprint head 18, and motion stage 20 is configured to move with respect to stage support 16 along X- and Y-axes. Radiation source 22 is coupled to system 10 to impinge actinic radiation upon motion stage 20. As further shown in FIG. 1, radiation source 22 is coupled to bridge 14, and includes power generator 23 connected to radiation source 22. An exemplary system is available under the trade name IMPRIO 100<sup>TM</sup> from Molecular Imprints, Inc. having a place of business at 1807-C Braker Lane, Suite 100, Austin, Texas 78758. The system description for the IMPRIO 100<sup>TM</sup> is available at [www.molecularimprints.com](http://www.molecularimprints.com) and is incorporated herein by reference.

**[0015]** Referring to FIGS. 1 and 2, connected to imprint head 18 is imprint template 26 having mold 28 thereon. Mold 28 includes a plurality of features defined by a plurality of spaced-apart recessions 28a and protrusions 28b. The plurality of features defines an original pattern that is to be transferred into substrate 31 positioned on motion stage 20. Substrate 31 may comprise a bare wafer or a wafer with one or more layers disposed thereon. To that end, imprint head 18 is adapted to move along the Z-axis and vary a distance "d" between mold 28 and substrate 31.

In this manner, features on mold 28 may be imprinted into a conformable region of substrate 31, discussed more fully below. Radiation source 22 is located so that mold 28 is positioned between radiation source 22 and substrate 31. As a result, mold 28 is fabricated from material that allows it to be substantially transparent to the radiation produced by radiation source 22.

**[0016]** Referring to FIGS. 2 and 3, a conformable region, such as imprinting layer 34, is disposed on a portion of surface 32 that presents a substantially planar profile. It should be understood that the conformable region may be formed using any known technique to produce conformable material on surface 32. In accordance with one embodiment of the present invention, the conformable region consists of imprinting layer 34 being deposited as a plurality of spaced-apart discrete droplets 36 of material 36a on substrate 31, discussed more fully below. Imprinting layer 34 is formed from a low molecular weight material 36a that is concurrently polymerized and cross-linked to record the original pattern therein, defining a recorded pattern. Material 36a is shown in FIG. 4 as being polymerized and cross-linked, forming cross-linked polymer material 36c. Cross-linking is shown at points 36b.

**[0017]** Referring to FIGS. 2, 3 and 5, the pattern recorded in imprinting layer 34 is produced, in part, by mechanical contact with mold 28. To that end, imprint head 18 reduces the distance "d" to allow imprinting layer 34 to come into mechanical contact with mold 28, spreading droplets 36 so as to form imprinting layer 34 with a contiguous formation of material 36a over surface 32. In one embodiment, distance "d" is reduced to allow sub-

portions 34a of imprinting layer 34 to ingress into and to fill recessions 28a.

**[0018]** To facilitate filling of recessions 28a, material 36a is provided with the requisite properties to completely fill recessions 28a while covering surface 32 with a contiguous formation of material 36a. In accordance with one embodiment of the present invention, sub-portions 34b of imprinting layer 34 in superimposition with protrusions 28b remain after the desired, usually minimum distance "d," has been reached, leaving sub-portions 34a with a thickness  $t_1$  and sub-portions 34b with a thickness,  $t_2$ . Thicknesses "t<sub>1</sub>" and "t<sub>2</sub>" may be any thickness desired, dependent upon the application.

**[0019]** Referring to FIGS. 2, 3 and 4, after a desired distance "d" has been reached, radiation source 22 produces actinic radiation that polymerizes and cross-links material 36a, forming polymer material 36c in which a substantial portion thereof is cross-linked. As a result, material 36a transforms to material 36c, which is a solid, forming imprinting layer 134, shown in FIG. 5. Specifically, material 36c is solidified to provide side 34c of imprinting layer 134 with a shape conforming to a shape of a surface 28c of mold 28, with imprinting layer 134 having recesses 30 (the bottom of the recesses may be referred to as a residual layer). After imprinting layer 134 is transformed to consist of material 36c, shown in FIG. 4, imprint head 18, shown in FIG. 2, is moved to increase distance "d" so that mold 28 and imprinting layer 134 are spaced-apart.

**[0020]** Referring to FIG. 5, additional processing may be employed to complete the patterning of substrate 31. For

example, substrate 31 and imprinting layer 134 may be etched to transfer the pattern of imprinting layer 134 into substrate 31, providing a patterned surface (not shown). To facilitate etching, the material from which imprinting layer 134 is formed may be varied to define a relative etch rate with respect to substrate 31, as desired.

**[0021]** To that end, etching may be performed in a two-step process. S.C. Johnson, T.C. Bailey, M.D. Dickey, B.J. Smith, E.K. Kim, A.T. Jamieson, N.A. Stacey, J.G. Ekerdt, and C.G. Willson describe suitable etch processes in an article entitled "Advances in Step and Flash Imprint Lithography," SPIE Microlithography Conference, February 2003, which is available on the Internet at [www.molecularimprints.com](http://www.molecularimprints.com), and is incorporated by reference herein. As set forth in the article, the first etch step, referred to as a "break-through etch," anisotropically removes residual cross-linked material 134 to break through to an underlying transfer layer (in this respect, better etch selectivity is enabled by keeping the residual layer small). The second etch step, referred to as a "transfer etch," uses the remaining pattern in cross-linked material 134 as an etch mask to transfer the pattern into the underlying transfer layer. In one embodiment, silicon in cross-link material 134, and the lack of silicon in the transfer layer, provides etch selectivity therebetween. In such an embodiment, the etching may be done in a LAM Research 9400SE obtained from Lam Research, Inc. of Fremont, California. For example, and without limitation, a halogen "breakthrough etch" may be utilized which comprises an anisotropic halogen reactive ion etch ("RIE") rich in fluorine, i.e., wherein at least one of the



precursors was a fluorine-containing material (for example, and without limitation, a combination of  $\text{CHF}_3$  and  $\text{O}_2$ , where the organosilicon nature of cross-linked material 134 may call for the use of a halogen gas). Other suitable halogen compounds include, for example, and without limitation,  $\text{CF}_4$ . This etch is similar to a standard  $\text{SiO}_2$  etch performed in modern integrated circuit processing. Next, an anisotropic oxygen reactive ion etch may be used to transfer the features to underlying substrate 31 wherein the remaining silicon containing features serve as an etch mask to transfer the pattern to underlying substrate 31. The "transfer etch" may be achieved, for example, and without limitation, with a standard, anisotropic, oxygen RIE processing tool. However, in general, any suitable etch process may be employed, dependent upon the etch rate desired and the underlying constituents that form substrate 31 and imprinting layer 134. Exemplary etch processes may include plasma etching, reactive ion etching, chemical wet etching and the like.

**[0022]** Referring to both FIGS. 1 and 2, exemplary radiation source 22 may produce ultraviolet radiation; however, any known radiation source may be employed. The selection of radiation employed to initiate the polymerization of the material in imprinting layer 34 is known to one skilled in the art and typically depends on the specific application which is desired. Furthermore, the plurality of features on mold 28 are shown as recessions 28a extending along a direction parallel to protrusions 28b that provide a cross-section of mold 28 with a shape of a battlement. However, recessions 28a and protrusions 28b may correspond to virtually any feature

required to create an integrated circuit and may be as small as a few tenths of nanometers.

**[0023]** Referring to FIGS. 1, 2 and 5, the pattern produced by the present patterning technique may be transferred into substrate 31 to provide features having aspect ratios as great as 30:1. To that end, one embodiment of mold 28 has recessions 28a defining an aspect ratio in a range of 1:1 to 10:1. Specifically, protrusions 28b have a width  $W_1$  in a range of about 10 nm to about 5000  $\mu\text{m}$ , and recessions 28a have a width  $W_2$  in a range of 10 nm to about 5000  $\mu\text{m}$ . As a result, mold 28 and/or template 26, may be formed from various conventional materials, such as, but not limited to, fused-silica, quartz, silicon, organic polymers, siloxane polymers, borosilicate glass, fluorocarbon polymers, metal, hardened sapphire and the like.

**[0024]** Referring to FIGS. 1, 2 and 3, the characteristics of material 36a are important to efficiently pattern substrate 31 in light of the deposition process employed. As mentioned above, material 36a is deposited on substrate 31 as a plurality of discrete and spaced-apart droplets 36. The combined volume of droplets 36 is such that material 36a is distributed appropriately over an area of surface 32 where imprinting layer 34 is to be formed. As a result, imprinting layer 34 is spread and patterned concurrently, with the pattern being subsequently set into imprinting layer 34 by exposure to radiation, such as ultraviolet radiation. As a result of the deposition process, it is desired that material 36a have certain characteristics to facilitate rapid and even spreading of material 36a in droplets 36 over surface 32 so that all

thicknesses  $t_1$  are substantially uniform and all thicknesses  $t_2$  are substantially uniform. The desirable characteristics include having a low viscosity, for example, and without limitation, in a range of about 0.5 to about 5 centepoise (cps), as well as the ability to wet surface of substrate 31 and mold 28 and to avoid subsequent pit or hole formation after polymerization. With these characteristics satisfied, imprinting layer 34 may be made sufficiently thin while avoiding formation of pits or holes in the thinner regions, such as sub-portions 34b, shown in FIG. 5. However, the characteristics of material 36a are process dependent and may vary as desired. For example, the viscosity may be 100 cps or greater.

**[0025]** The constituent components that form material 36a to provide the aforementioned characteristics may differ. This results from substrate 31 being formed from a number of different materials. As a result, the chemical composition of surface 32 varies dependent upon the material from which substrate 31 is formed. For example, substrate 31 may be formed from, silica, indium phosphide, lithium niobate, lithium tantalate, silicon, plastics, gallium arsenide, mercury telluride, and the like. Additionally, substrate 31 may include one or more layers in sub-portion 34b, for example, dielectric layer, metal layer, semiconductor layer, planarization layer and the like.

**[0026]** Referring to FIGS. 2, 3 and 4, it is desired, however, that material 36a include components to satisfy desired release characteristics when mold 28 interfaces with both material 36a and material 36c. Specifically, to ensure efficient filling of features of mold 28, it is

desired that the interface of mold 28 and material 36a be established so that wetting of mold 28 by imprinting material 36a is facilitated. However, once material 36a is solidified into material 36c, material 36a should preferentially adhere to surface 32 of substrate 31 and easily release from mold 28. In this fashion, distortions in the pattern recorded in solidified material 36c are minimized. The preferential adhesion of material 36c to substrate 31 is referred to as release characteristics. The release characteristics of imprinting material 36c are measured employing an adhesion test described by Taniguchi et al. in Measurement of Adhesive Force Between Mold and Photocurable Resin in Imprint Technology, Japanese Journal of Applied Physics, part 1, vol. 40, beginning at page 4194 (2002). It has been discovered that desirable values for these release characteristics are: (a) an adhesion force to mold 28, for example, and without limitation, of about 0.15 kg or less; and (b) an adhesion force to substrate 31, for example, and without limitation, of about 1.14 kg or more. It is desired that the ratio of adhesion forces, i.e., the adhesion force of substrate 31/the adhesion force of mold 28 [hereinafter referred to as the adhesion ratio] be 5 or greater.

**[0027]** In addition to the above-described release characteristics, when designing an imprinting material for use in imprint lithography, further considerations include: (a) low viscosity, for example, and without limitation, a viscosity of 5 centipoise or less, to enable desirable wetting and spreading on the substrate and rapid fill of the features on the imprint template (it is better if the viscosity is sufficiently low so that minimal pressure (for

example, and without limitation, a pressure of about 2-4 psi) with minimal or no additional heating to move the imprinting material into features of an imprint template); (b) low vapor pressure so that there is little evaporation (evaporation is a problem since the droplets of imprinting material may be on the order of 80 pico-liters, and this results in droplets having a large ratio between surface area and volume); (c) the use of a suitable initiator to initiate polymerization upon exposure to actinic radiation, e.g., UV radiation, thermal radiation and the like; (d) a monomer component that satisfies the low viscosity characteristics in a liquid state of the composition and provide suitable mechanical strength in a solid cured state of the composition; and (e) silylated monomers to provide the silicon desired to provide etch selectivity.

**[0028]** In addition to the above, we have discovered macroscopic mechanical properties of a polymerized imprinting material that is desired to be taken into consideration when designing an appropriate imprinting material. These include: (a) tensile modulus, for example, and without limitation, of about 100 - 400 MPa or greater - typically, the higher the better; (b) break stress, for example, and without limitation, of about 3- 12 MPa or greater -typically, the higher the better; and (c) elongation at break, for example, and without limitation, of 2% or more.

**[0029]** The design of a suitable imprinting material is an iterative procedure that focuses on materials in the following order: (a) formulation volatility (i.e., use of low vapor pressure components); (b) viscosity control (i.e., use of low viscosity components); (c) rapid

polymerization kinetics, e.g., less than a minute and more suitable less than two seconds; (d) component miscibility; (e) mechanical properties (tensile modulus, break stress, elongation at break, and  $T_g$ ); (f) wetting and spreading (fluid flow behavior); and (g) adhesions (low to the imprint template and high to the substrate).

**[0030]** The requirement of low viscosity may restrict the choice of components used to fabricate the imprinting material. To build up the strength of the polymerized material based on non-polar monomers, one may compromise and add higher viscosity components. For example, identified is isobornyl acrylate as the building block with silicon containing acrylate monomer components being added to provide silicon for etch selectivity. Typically, the high viscosity components are added judiciously to maintain an overall viscosity of imprinting material 36a to be less than 5 cps.

**[0031]** We have designed an imprinting material by taking into account the design considerations set forth above, and adding the use of a fluorinated surfactant to satisfy desired release characteristics. An exemplary composition for material 36a that utilizes a fluorinated surfactant is produced by mixing (with exemplary proportions being given in weight): (i) acryloxymethylpentamethyldisiloxane (for example, and without limitation, about 37 gm) which is available under the designation XG-1064 from Gelest, Inc. of Morrisville, Pennsylvania, (ii) isobornyl acrylate ("IBOA") (for example, and without limitation, about 42 gm) that is available from Aldrich Chemical Company of Milwaukee, Wisconsin, (iii) ethylene glycol diacrylate (for example, and without limitation, about 18 gm) that is

available from Aldrich Chemical Company of Milwaukee, Wisconsin, (iv) a UV photoinitiator, for example, and without limitation, 2-hydroxy-2-methyl-1-phenyl-propan-1-one (for example, and without limitation, about 3 gm) that is available under the designation Darocur 1173 from CIBA® of Tarrytown, New York), and (v) FSO-100 (for example, and without limitation, about 0.5 gm) where FSO-100 is a surfactant that is available under the designation ZONYL® FSO-100 from DUPONT™ (FSO-100 has a general structure of  $R_1R_2$  where  $R_1 = F(CF_2CF_2)_Y$ , with Y being in a range of 1 to 7, inclusive and  $R_2 = CH_2CH_2O(CH_2CH_2O)_XH$ , where X is in a range of 0 to 15, inclusive).

**[0032]** An alternative composition for material 36a is produced by mixing (with exemplary proportions being given in weight): (i) acryloxymethylpentamethyldisiloxane (for example, and without limitation, about 37 gm) which is available under the designation XG-1064 from Gelest, Inc. of Morrisville, Pennsylvania, (ii) isobornyl acrylate ("IBOA") (for example, and without limitation, about 42 gm) that is available from Aldrich Chemical Company of Milwaukee, Wisconsin, (iii) ethylene glycol diacrylate (for example, and without limitation, about 18 gm) that is available from Aldrich Chemical Company of Milwaukee, Wisconsin, (iv) a UV photoinitiator, for example, and without limitation, 2-hydroxy-2-methyl-1-phenyl-propan-1-one (for example, and without limitation, about 3 gm) that is available under the designation Darocur 1173 from CIBA® of Tarrytown, New York), and (v) FC4432 (for example, and without limitation, about 0.5 gm) where FC4432 is a polymeric surfactant that

is available from 3M Company under the designation FLUORAD® FC4432.

**[0033]** Another alternative composition for material 36a is produced by mixing (with exemplary proportions being given in weight): (i) acryloxymethylpentamethyldisiloxane (for example, and without limitation, about 37 gm) which is available under the designation XG-1064 from Gelest, Inc. of Morrisville, Pennsylvania, (ii) isobornyl acrylate ("IBOA") (for example, and without limitation, about 42 gm) that is available from Aldrich Chemical Company of Milwaukee, Wisconsin, (iii) ethylene glycol diacrylate (for example, and without limitation, about 18 gm) that is available from Aldrich Chemical Company of Milwaukee, Wisconsin, (iv) a UV photoinitiator, for example, and without limitation, 2-hydroxy-2-methyl-1-phenyl-propan-1-one (for example, and without limitation, about 3 gm) that is available under the designation Darocur 1173 from CIBA® of Tarrytown, New York), and (v) FC4430 (for example, and without limitation, about 0.5 gm) where FC4430 is a polymeric surfactant that is available from 3M Company under the designation FLUORAD® FC4430.

**[0034]** In addition to the silicon containing composition for material 36a, a non-silicon-containing composition for material 36a may be employed. An exemplary non-silicon-containing composition includes i) approximately 55 gm isobornyl acrylate, ii) approximately 27gm n-hexyl acrylate, iii) approximately 15gm ethylene glycol diacrylate, iv) approximately 0.5gm of the ZONYL® FSO-100 surfactant, and v) the DAROCUR® initiator that is approximately 3gm of the composition.



**[0035]** An additional non-silicon-containing composition for material 36a, includes i) approximately 55 gm isobornyl acrylate, ii) approximately 27gm n-hexyl acrylate, iii) approximately 15gm ethylene glycol diacrylate, iv) approximately 0.5gm of the FC4432 surfactant, and v) the DAROCUR® initiator that is approximately 3gm of the composition.

**[0036]** Another non-silicon-containing composition for material 36a includes i) approximately 55 gm isobornyl acrylate, ii) approximately 27gm n-hexyl acrylate, iii) approximately 15gm ethylene glycol diacrylate, iv) approximately 0.5gm of the FC4430 surfactant, and v) the DAROCUR® initiator that is approximately 3gm of the composition. Each of the above-identified compositions also includes stabilizers that are well known in the chemical art to increase the operational life of the composition.

**[0037]** In yet another example of a non-silicon-containing composition included are i) approximately 47 gm of isobornyl acrylate, ii) approximately 25gm of n-hexyl acrylate, iii) approximately 25gm of ethylene glycol diacrylate, iv) approximately 0.5gm of the ZONYL® FSO-100 surfactant, and v) the DAROCUR® initiator that is approximately 3gm of the composition.

**[0038]** In yet another non-silicon-containing composition for material 36a a surfactant mixture is included that comprises of a non-fluorinated surfactant and a fluorinated surfactant. An exemplary composition includes i) approximately 55 gm isobornyl acrylate, ii) approximately 27gm n-hexyl acrylate, iii) approximately 15gm ethylene glycol diacrylate, and iv) the DAROCUR® initiator that is

approximately 3gm of the composition and 0.5gm of a surfactant mixture. An exemplary surfactant mixture consists of 0.25gm of FC4432 and 0.25gm of a tri-siloxane surfactant available under the designation Sylgard® 309 from Dow Corning Corporation of Auburn, Michigan.

**[0039]** Similarly, the surfactant mixture may be used in conjunction with a silicon-containing composition described above. An exemplary composition includes (i) acryloxymethylpentamethyldisiloxane (for example, and without limitation, about 37 gm) (ii) isobornyl acrylate ("IBOA") (for example, and without limitation, about 42 gm) (iii) ethylene glycol diacrylate (for example, and without limitation, about 18 gm), (iv) the Darocur 1173 initiator (for example and without limitation 3gm) and (v) an exemplary surfactant mixture consisting of 0.25gm of FC4432 and 0.25gm of a tri-siloxane surfactant available under the designation Sylgard® 309 from Dow Corning Corporation of Auburn, Michigan.

**[0040]** each of the above-identified compositions may also include stabilizers that are well known in the chemical art to increase the operational life of the composition. The surfactant comprises less than 1% of the imprinting material. However, the percentage of the surfactant may be greater than 1%.

**[0041]** An advantage provided by the above-described imprinting material is that they abrogates the need for an *a priori* release layer, i.e., a separate hydrophobic and/or low surface energy release layer disposed on imprint template 28. Specifically, the inclusion of the surfactants in the compositions provide desirable release properties to mold 28 and imprinting layer 34 so as to

reduce, if not avoid, degradation of, or distortions in, the pattern recorded in the imprinting layer 34.

**[0042]** Referring to FIG. 6, it is believed that surfactant molecules in droplets 36 of the imprinting material preferentially move toward the gas-liquid interface in less than about 1 second. As such, it is believed that droplets 36 have a higher concentration of the surfactant in region 136 as compared to region 137 in which the polymerizable components are concentrated. It is believed that this is the result of an energy minimization process wherein the surfactant tends to move to the gas-liquid interface and its hydrophobic end aligns towards the gas. For example, it is believed that the hydrophobic end of the surfactant is aligned to project out of the liquid and into the gas, and the hydrophilic end is aligned to project into the liquid. However, when the imprinting material contacts the surface of the imprint template, it is believed that exposed silanol bonds on the surface of the imprint template cause the hydrophilic end of the surfactant molecule to flip and to contact the exposed silanol bonds so that the hydrophobic end faces downwardly e.g., outwardly from the surface of the imprint template to enable adhesion reduction. It is further believed that weakly bound surfactant lamella may also be formed at the surface of the imprint template, which lamella may comprise, for example, two (2) layers of surfactant molecules.

**[0043]** Referring to FIG. 2, an additional advantage provided by the above-described imprinting material is that template cleaning and preparation time is shortened; therefore, the overall process is simplified. Of course,

the above-described imprinting material may be employed with an *a priori* release layer, such as those known in the prior art.

**[0044]** Another manner by which to improve the release properties of mold 28 includes pre-conditioning the pattern of mold 28 by exposing the same to a conditioning mixture including an additive that will remain on mold 28 to reduce the surface energy of the mold surface. An exemplary additive is a surfactant.

**[0045]** The above-described imprinting materials are useful in providing substantially high feature fidelity imprint lithography, while providing suitable operational life to an imprint template. For example, a imprint template having a patterning area, i.e., mold, of 25 X 25 mm having 40 to 50 nm features was employed to generate five hundred (500) imprints with minimal pattern feature degradation and distortion.

**[0046]** An exemplary imprinting method using the imprinting material described above includes as a first step, pretreating the surface of a quartz imprint template to create hydrophilic bonds at the surface, for example, and without limitation, silanol (Si-OH) bonds. In accordance with one or more embodiments of the present invention, the surface of the imprint template is dipped in a 2.5:1 solution of  $H_2SO_4$  and  $H_2O_2$  to hydrolyze the surface, i.e., to create silanol bonds at the surface. This is referred to as piranha cleaning.

**[0047]** As a next step, the surface is further pre-treated by spraying the surface of the imprint template with a diluted surfactant solution (for example, and without limitation, 0.1% in isopropyl alcohol (IPA)). The

surfactant efficiently at the surface of the imprint template with hydrophobic ends projecting outwardly from the surface. Such alignment is promoted by piranha cleaning the surface to create silanol bonds on the surface. Exposure of the surface of the imprint template may be achieved by virtually any method known in the art, including dipping the surface into a volume of pre-treatment solution, wiping the surface with a cloth saturated with pre-treatment solution, and spraying a stream of pre-treatment solution onto the surface. The IPA in the pre-treatment solution may be allowed to evaporate before using the mold 28. In this manner, the IPA facilitates removing undesired contaminants from the surface while leaving the surfactant adsorbed thereto. Because the surfactant includes a hydrophobic end and a hydrophilic end, the silanol bonds promote alignment of the surfactant so that the hydrophilic end "attaches" to the -OH end of the silanol bonds, and the hydrophobic end points away from the surface. In a next step, a gap between the imprint template and the substrate is purged of air using, for example, and without limitation, a ~ 5 psi helium purge.

**[0048]** In a next step, the imprinting material containing the surfactant is applied to the substrate, for example, and without limitation, by placing a pattern of substantially equidistant droplets of the following imprinting material on the substrate, or by spin-coating, or by any other method known to those of ordinary skill in the art. In this example, the substrate was covered with a transfer layer whose top layer was a cross-linked BARC material (BARC or "bottom antireflective coating" is an

organic antireflective coating that is typically produced by a spin-on process). The BARC layer was used to prevent intermixing between an imprinting material and a transfer layer, which intermixing may be particularly problematic when using an imprinting material comprised of low viscosity components used herein, because such components have solvency toward many polymers. Substantial intermixing may cause problems, such as, for example, and without limitation, distortion of features during subsequent etching processes. This can be particularly problematic when feature thicknesses are as small as 50 to 100 nm. Next, the familiar steps of imprint lithography are carried out, i.e., exposure to actinic radiation to polymerize the imprinting material; separation of the imprint template and the substrate; and selective etching to transfer the feature pattern to the substrate.

**[0049]** It is believed that even when pre-treating the surface of the imprint template as described above utilizing one or more surfactants, the one or more surfactants are adsorbed to the silanol surface of the imprint template ultimately become abraded away. However, as was described above, the surfactant contained in the imprinting material rapidly comes to the gas-liquid surface of the droplets, and the surface of the imprint template is re-coated as a normal consequence of imprinting. As such, in accordance with one or more embodiments of the present invention, the pre-treatment step of applying the surfactant solution to the surface of the imprint template may be eliminated. In fact, in accordance with one or more further embodiments of the present invention, the imprint template may be contacted a few times with the imprinting

material as a replacement for the pre-treatment step of applying the surfactant solution to the surface.

**[0050]** The embodiments of the present invention described above are exemplary. Many changes and modifications may be made to the disclosure recited above, while remaining within the scope of the invention. The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.